SCIENCE

[Entered at the Post-Office of New York, N.Y., as Second-Class Matter.]

A WEEKLY NEWSPAPER OF ALL THE ARTS AND SCIENCES.

EIGHTH YEAR.
VOL. XVI. No. 401.

NEW YORK, OCTOBER 10, 1890.

SINGLE COPIES, TEN CENTS.
$3.50 PER YEAR, IN ADVANCE.

THE ELECTRO-MAGNET.[1]

Introductory.

AMONG the great inventions which have originated in the lecture-room in which we are met are two of special interest to electricians,—the application of gutta-percha to the purpose of submarine telegraph-cables, and the electro-magnet. This latter invention was first publicly described from the very platform on which I stand, on May 23, 1825, by William Sturgeon, whose paper is to be found in the forty-third volume of the "Transactions of the Society of Arts." For this invention we may rightfully claim the very highest place. Electrical engineering, the latest and most vigorous offshoot of applied science, embraces many branches. The dynamo for generating electric currents, the motor for transforming their energy back into work, the arc-lamp, the electric bell, the telephone, the recent electro-magnetic machinery for coal-mining, for the separation of ore, and many other electro-mechanical contrivances, come within the purview of the electrical engineer. In every one of these, and in many more of the useful applications of electricity, the central organ is an electro-magnet. By means of this simple and familiar contrivance,—an iron core surrounded by a copper-wire coil,—mechanical actions are produced at will, at a distance, under control, by the agency of electric currents. These mechanical actions are known to vary with the mass, form, and quality of the iron core, the quantity and disposition of the copper wire wound upon it, the quantity of electric current circulating around it, the form, quality, and distance of the iron armature upon which it acts. But the laws which govern the mechanical action in relation to these various matters are by no means well known; and, indeed, several of them have long been a matter of dispute. Gradually, however, that which has been vague and indeterminate becomes clear and precise. The laws of the steady circulation of electric currents, at one time altogether obscure, were cleared up by the discovery of the famous law of Ohm. Their extension to the case of rapidly interrupted currents, such as are used in telegraphic working, was discovered by Helmholtz; while to Maxwell is due their further extension to alternating, or, as they are sometimes called, undulatory currents. All this was purely electric work. But the law of the electro-magnet was still undiscovered; the magnetic part of the problem was still buried in obscurity. The only exact reasoning about magnetism dealt with problems of another kind; it was couched in language of a misleading character; for the practical problems connected with the electro-magnet it was worse than useless,—the doctrine of two magnetic fluids distributed over the end surfaces of magnets, which, under the sanction of the great names of Coulomb, of Poisson, and of Laplace, had unfortunately become recognized as an accepted part of science, along with the law of inverse squares. How greatly the progress of electro-magnetic science has been impeded and retarded by the weight of these great names, it is impossible now to gauge. We now know that for all purposes, save only those whose value lies in the domain of abstract mathematics, the doctrine of the two magnetic fluids is false and misleading. We know that magnetism, so far from residing on the end or surface of the magnet, is a property resident throughout the mass; that the internal, not the external, magnetization is the important fact to be considered; that the so-called free magnetism on the surface is, as it were, an accidental phenomenon; that the magnet is really most highly magnetized at those parts where there is least surface magnetization; finally, that the doctrine of surface distribution of fluids is absolutely incompetent to afford a basis of calculation such as is required by the electrical engineer. He requires rules to enable him not only to predict the lifting power of a given electro-magnet, but also to guide him in designing and constructing electro-magnets of special forms suitable for the various cases that arise in his practice. He wants in one place a strong electro-magnet to hold on to its armature like a limpet to its native rock; in another case he desires a magnet having a very long range of attraction, and wants a rule to guide him to the best design; in another he wants a special form having the most rapid action attainable; in yet another he must sacrifice every thing else to attain maximum action with minimum weight. Toward the solution of such practical problems as these, the old theory of magnetism offered not the slightest aid. Its array of mathematical symbols was a mockery. It was as though an engineer asking for rules to enable him to design the cylinder and piston of an engine were confronted with receipts how to estimate the cost of painting it.

Gradually, however, new light dawned. It became customary, in spite of the mathematicians, to regard the magnetism of a magnet as something that traverses or circulates around a definite path, flowing more freely through such substances as iron than through other relatively non-magnetic materials. Analogies between the flow of electricity in an electrically conducting circuit, and the passage of magnetic lines of force through circuits possessing magnetic conductivity, forced themselves upon the minds of experimenters, and compelled a mode of thought quite other than the pre-

[1] Lecture delivered Jan. 20, 1890, by Professor Silvanus P. Thompson, before the Society of Arts, London.

viously accepted. So far back as 1821, Cumming[1] experimented on magnetic conductivity. The idea of a magnetic circuit was more or less familiar to Ritchie,[2] Sturgeon,[3] Dove,[4] Dub,[5] and De la Rive,[6] the last named of whom explicitly uses the phrase "a closed magnetic circuit." Joule[7] found the maximum power of an electro-magnet to be proportional to "the least sectional area of the entire magnetic circuit," and he considered the resistance to induction as proportional to the length of the magnetic circuit. Indeed, there are to be found scattered in Joule's writings on the subject of magnetism some five or six sentences, which, if collected together, constitute a very full statement of the whole matter. Faraday[8] considered that he had proved that each demagnetic line of force constitutes a closed curve; that the path of these closed curves depended on the magnetic conductivity of the masses disposed in proximity; that the lines of magnetic force were strictly analogous to the lines of electric flow in an electric circuit. He spoke of a magnet surrounded by air being like unto a voltaic battery immersed in water or other electrolyte. He even saw the existence of a power analogous to that of electro-motive force in electric circuits, though the name "magneto-motive force" is of more recent origin. The notion of magnetic conductivity is to be found in Maxwell's great treatise (vol. ii. p. 51), but is only briefly mentioned. Rowland,[9] in 1873, expressly adopted the reasoning and language of Faraday's method in the working-out of some new results on magnetic permeability, and pointed out that the flow of magnetic lines of force through a bar could be subjected to exact calculation. The elementary law, he says, "is similar to the law of Ohm." According to Rowland, the "magnetizing force of helix" was to be divided by the "resistance to the lines of force,"—a calculation for magnetic circuits which every electrician will recognize as precisely as Ohm's law for electric circuits. He applied the calculations to determine the permeability of certain specimens of iron, steel, and nickel. In 1882,[10] and again in 1883, Mr. R. H. M. Bosanquet[11] brought out at greater length a similar argument, employing the extremely apt term "magneto-motive force" to connote the force tending to drive the magnetic lines of induction through the "magnetic resistance," or, as it will be frequently called in these lectures, the "magnetic reluctance" of the circuit. In these papers the calculations are reduced to a system, and deal not only with the specific properties of iron, but with problems arising out of the shape of the iron. Bosanquet shows how to calculate the several resistances (or reluctances) of the separate parts of the circuit, and then add them together to obtain the total resistance (or reluctance) of the magnetic circuit.

1 Cambridge Philosophical Transactions, April 2, 1821.

2 Philosophical Magazine, series iii. vol. iii. p. 122.

3 Annals of Electricity, xii. p. 217.

4 Poggendorf's Annalen, 1833, xxix. p. 462; 1838, xliii. p. 517.

5 Dub's Elektromagnetismus (ed. 1861), p. 401; Poggendorf's Annalen, 1853, xc. p. 440.

6 De la Rive's Treatise on Electricity (Walker's translation), i. p. 292.

7 Annals of Electricity, 1839, iv. p. 59; *Ibid*, 1841, v. p. 195; Scientific Papers, pp. 8, 34, 35, 36

8 Experimental Researches, iii. arts. 3117, 3228, 3230, 3260, 3271, 3276, 3294, and 3361.

9 Philosophical Magazine, series iv. vol. xlvi. August, 1873, "On Magnetic Permeability and the Maximum of Magnetism of Iron, Steel, and Nickel."

10 Proceedings of the Royal Society, xxxiv. p. 445, December, 1882

11 Philosophical Magazine, series v. vol. xv. p. 205, March, 1883, 'On Magneto-Motive Force;" *Ibid*, xix. February, 1885; Proceedings of the Royal Society, 1883, No. 223; Electrician, xiv. p. 291, Feb. 14, 1885.

Prior to this, however, the principle of the magnetic circuit had been seized upon by Lord Elphinstone and Mr. Vincent, who proposed to apply it in the construction of the dynamo-electric machines. On two occasions[1] they communicated to the Royal Society the results of experiments to show that the same exciting current would evoke a larger amount of magnetism in a given iron structure if that iron structure formed a closed magnetic circuit than if it were otherwise disposed.

In recent years the notion of the magnetic circuit has been vigorously taken up by the designers of dynamo-machines, who indeed base the calculation of their designs upon this all-important principle. Having this, they need no laws of inverse squares of distances, no magnetic moments, none of the elaborate expressions for surface distribution of magnetism, none of the ancient paraphernalia of the last century. The simple law of the magnetic circuit and a knowledge of the properties of iron are practically all they need. About four years ago, much was done by Mr. Gisbert Kapp[2] and by Drs. J. and E. Hopkinson[3] in the application of these considerations to the design of dynamo-machines, which previously had been a matter of empirical practice. To this end the formulæ of Professor Forbes[4] for calculating magnetic leakage, and the researches of Professors Ayrton and Perry[5] on magnetic shunts, contributed a not unimportant share. As the result of the advances made at that time, the subject of dynamo design was reduced to an exact science.

It is the aim and object of the present course of lectures to show how the same considerations which have been applied with such great success to the subject of the design of dynamo-electric machines may be applied to the study of the electro-magnet. The theory and practice of the design and construction of electro-magnets will thus be placed, once for all, upon a rational basis. Definite rules will be laid down for the guidance of the constructor, directing him as to the proper dimensions and form of iron to be chosen, and as to the proper size and amount of copper wire to be wound upon it in order to produce any desired result.

First, however, an historical account of the invention will be given, followed by a number of general considerations respecting the uses and forms of electro-magnets. These will be followed by a discussion of the magnetic properties of iron and steel and other materials, some account being added of the methods used for determining the magnetic permeability of various brands of iron at different degrees of saturation. Tabular information is given as to the results found by different observers. In connection with the magnetic properties of iron, the phenomenon of magnetic hysteresis is also described and discussed. The principle of the magnetic circuit is then discussed with numerical examples, and a number of experimental data respecting the performance of electro-magnets are adduced, in particular those bearing upon the tractive power of electro-magnets. The law of traction between an electro-magnet and its armature

1 Proceedings of the Royal Society, 1879, xxix. p. 292; *Ibid*, 1880, xxx. p. 287; Electrical Review, 1880, viii. p. 134.

2 The Electrician, 1885-86, xiv. xv. xvi.; Proceedings of the Institute of Civil Engineers, 1885-86, lxxxiii.; Journal of the Society of Telegraphic Engineers, 1886, xv. p. 524.

3 Philosophical Transactions, 1886, part i. p. 331; The Electrician, 1886, xviii. pp. 39, 63, 86.

4 Journal of the Society of Telegraphic Engineers, 1886, xv. p. 555.

5 *Ibid*, p. 530.

is then laid down, followed by the rules for predetermining the iron cores and copper coils required to give any prescribed tractive force.

Then comes the extension of the calculation of the magnetic circuit to those cases where there is an air-gap between the poles of the magnet and the armature, and where, in consequence, there is leakage of the magnetic lines from pole to pole. The rules for calculating the winding of the copper coils are stated, and the limiting relation between the magnetizing power of the coil and the heating effect of the current in it is explained. After this comes a detailed discussion of the special varieties of form that must be given to electro-magnets in order to adapt them to special services. Those which are designed for maximum traction, for quickest action, for longest range, for greatest economy when used in continuous daily service, for working in series with constant current, for use in parallel at constant pressure, and those for use with alternate currents, are separately considered.

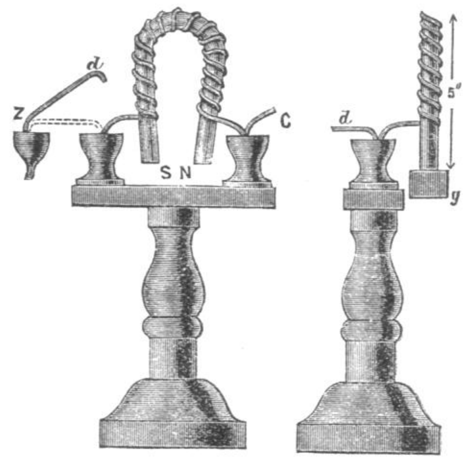
Lastly, some account is given of the various forms of electro-magnetic mechanism which have arisen in connection with the invention of the electro-magnet. The plunger and coil is specially considered as constituting a species of electro-magnet adapted for a long range of motion. Modes of mechanically securing long range for electro-magnets, and of equalizing their pull over the range of motion of the armature, are also described. The analogies between sundry electro-mechanical movements and the corresponding pieces of ordinary mechanism are traced out. The course is concluded by a consideration of the various modes of preventing or minimizing the sparks which occur in the circuits in which electro-magnets are used.

Historical Sketch.

The effect which an electric current, flowing in a wire, can exercise upon a neighboring compass-needle was discovered by Oersted in 1820.[1] This first announcement of the possession of magnetic properties by an electric current was followed speedily by the researches of Ampère,[2] Arago,[3] Davy,[4] and by the devices of several other experimenters, including De la Rive's[5] floating battery and coil, Schweigger's[5] multiplier, Cumming's[6] galvanometer, Faraday's[7] apparatus for rotation of a permanent magnet, Marsh's[8] vibrating pendulum, and Barlow's[8] rotating star-wheel. But it was not until 1825 that the electro-magnet was invented. Davy had, indeed, in 1821, surrounded with temporary coils of wire the steel needles upon which he was experimenting, and had shown that the flow of electricity around the coil could confer magnetic power upon the steel needles. But from this experiment it was a grand step forward to the discovery that a core of soft iron, surrounded by its own appropriate coil of copper, could be made to act not only as a powerful magnet, but as a magnet whose power could be turned on or off at will, could be augmented to any desired degree, and could be set into action and controlled from a practically unlimited distance.

[1] Thomson's Annals of Philosophy, October, 1820.
[2] Ann. de Chim. et de Physique, 1820, xv. pp. 59, 170.
[3] *Ibid*, p. 93.
[4] Philosophical Transactions, 1821.
[5] Bibliothèque Universelle, March, 1821.
[6] Cambridge Philosophical Transactions, 1821.
[7] Quarterly Journal of Science, September, 1821.
[8] Barlow's Magnetic Attractions, 1823 (2d ed.).

The electro-magnet, in the form which can first claim recognition for these qualities, was devised by William Sturgeon,[1] and is described by him in the paper which he contributed to the "Proceedings of the Society of Arts" in 1825, accompanying a set of improved apparatus for electro-magnetic experiments.[2] The Society of Arts rewarded Sturgeon's labors by awarding him the silver medal of the society and a premium of thirty guineas. Among this set of apparatus are two electro-magnets,—one of horseshoe shape (Figs. 1 and 2), and one a straight bar (Fig. 3). It will be seen that the former figures represent an electro-magnet consisting of a bent iron rod about one foot long, and half an inch in diameter, varnished over, and then coiled with a single left handed spiral of stout uncovered copper wire of 18 turns. This coil was found appropriate to the particular battery which Sturgeon preferred, namely, a single cell containing a spirally enrolled pair of zinc and copper plates of large area (about 130 square inches) immersed in acid; which cell, having small internal resistance, would yield a large quantity of current when connected to a circuit of



FIGS. 1 AND 2.—STURGEON'S FIRST ELECTRO-MAGNET.

small resistance. The ends of the copper wire were brought out sideways, and bent down so as to dip into two deep connecting cups, marked *Z* and *C*, fixed upon a wooden stand. These cups, which were of wood, served as supports to hold up the electro-magnet, and, having mercury in them, served also to make good electrical connection. In Fig. 2 the mag-

[1] William Sturgeon, the inventor of the electro-magnet, was born at Whittington, in Lancashire, in 1783. Apprenticed as a boy to the trade of a shoemaker, at the age of nineteen he joined the Westmoreland Militia, and two years later enlisted into the Royal Artillery, thus gaining the chance of learning something of science, and having leisure in which to pursue his absorbing passion for chemical and physical experiments. He was forty-two years of age when he made his great, though at the time unrecognized, invention. At the date of his researches in electro-magnetism he was resident at 8 Artillery Place, Woolwich, at which place he was the associate of Marsh, and was intimate with Barlow, Christie, and Gregory, who interested themselves in his work. In 1835 he presented a paper to the Royal Society containing descriptions, *inter alia*, of a magneto-electric machine with longitudinally wound armature, and with a commutator consisting of half disks of metal. For some reason this paper was not admitted to the Philosophical Transactions. He afterwards printed it in full, without alteration, in his volume of Scientific Researches, published by subscription in 1850. From 1836 to 1843 he conducted the Annals of Electricity. He had now removed to Manchester, where he lectured on electricity at the Royal Victoria Gallery. He died at Prestwich, near Manchester, in 1850. There is a tablet to his memory in the church at Kirkby Lonsdale, from which town the village of Whittington is distant about two miles. A portrait of Sturgeon in oils, said to be an excellent likeness, is believed still to be in existence; but all inquiries as to its whereabouts have proved unavailing. At the present moment, so far as I am aware, the scientific world is absolutely without a portrait of the inventor of the electro-magnet.

[2] Transactions of the Society of Arts, 1825, xliii. p. 38.

net is seen sideways, supporting a bar of iron, y. The circuit was completed to the battery through a connecting wire, d, which could be lifted out of the cup Z, so breaking circuit when desired, and allowing the weight to drop. Sturgeon added in his explanatory remarks that the poles, N and S, of the magnet will be reversed if you wrap the copper wire about the rod as a right-handed screw instead of a left-handed one, or, more simply, by reversing the connec-

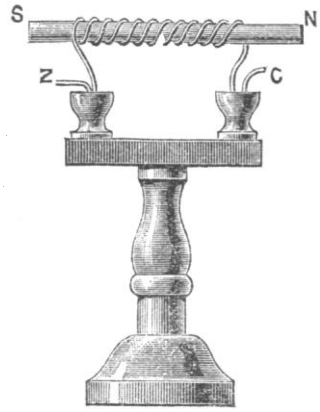


FIG. 3.—STURGEON'S STRAIGHT-BAR ELECTRO-MAGNET.

tions with the battery, by causing the wire that dips into the Z cup to dip into the C cup, and *vice versa*. This electro-magnet was capable of supporting nine pounds when thus excited.

Fig. 3 shows another arrangement to fit on the same stand. This arrangement communicates magnetism to hardened steel bars as soon as they are put in, and renders soft iron within it magnetic during the time of action. It only differs

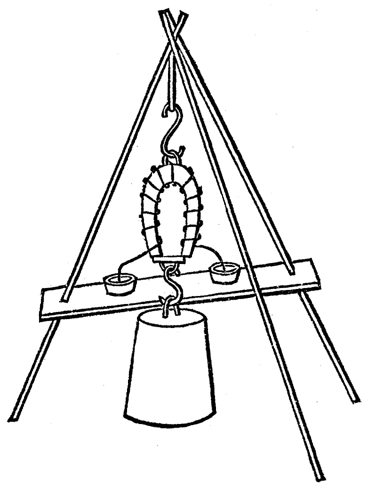


FIG. 4.—STURGEON'S LECTURE-TABLE ELECTRO-MAGNET.

from Figs. 1 and 2 in being straight, and thereby allows the steel or iron bars to slide in and out.

For this piece of apparatus and other adjuncts accompanying it, all of which are described in the society's "Transactions" for 1825, Sturgeon, as already stated, was awarded the society's silver medal and a premium of thirty guineas. The apparatus was deposited in the museum of the society, which therefore might be supposed to be the proud possessor of the first electro-magnet ever constructed. Alas for the vanity of human affairs! the society's museum of apparatus has long been dispersed, this priceless relic having been either made over to the now defunct Patent Office Museum, or otherwise lost sight of.

Sturgeon's first electro-magnet, the core of which weighed about 7 ounces, was able to sustain a load of 9 pounds, or about twenty times its own weight. At the time it was considered a truly remarkable performance. Its single layer of stout copper wire was well adapted to the battery employed, a single cell of Sturgeon's own particular construction having a surface of 130 square inches, and therefore of small internal resistance. Subsequently, in the hands of Joule, the same electro-magnet sustained a load of 50 pounds, or about a hundred and fourteen times its own weight. Writing in 1832 about his apparatus of 1825, Sturgeon used the following magniloquent language:—

"When first I showed that the magnetic energies of a galvanic conducting wire are more conspicuously exhibited by exercising them on soft iron than on hard steel, my experiments were limited to small masses, generally to a few inches of rod-iron about half an inch in diameter. Some of those pieces were employed while straight, and others were bent into the form of a horseshoe magnet, each piece being encompassed by a spiral conductor of copper wire. The magnetic energies developed by these simple arrangements are of a very distinguished and exalted character, as is conspicuously manifested by the suspension of a considerable weight at the poles during the period of excitation by the electric influence.

"An unparalleled transiliency of magnetic action is also displayed in soft iron by an instantaneous transition from a state of total inactivity to that of vigorous polarity, and also by a simultaneous reciprocity of polarity in the extremities of the bar,—versatilities in this branch of physics for the display of which soft iron is pre-eminently qualified, and which, by the agency of electricity, become demonstrable with the celerity of thought, and illustrated by experiments the most splendid in magnetics. It is, moreover, abundantly manifested by ample experiments that galvanic electricity exercises a superlative degree of excitation on the latent magnetism of soft iron, and calls for its recondite powers with astonishing promptitude, to an intensity of action far surpassing any thing which can be accomplished by any known application of the most vigorous permanent magnet, or by any other mode of experimenting hitherto discovered. It has been observed, however, by experimenting on different pieces selected from various sources, that, notwithstanding the greatest care be observed in preparing them of a uniform figure and dimensions, there appears a considerable difference in the susceptibility which they individually possess of developing the magnet powers, much of which depends upon the manner of treatment at the forge, as well as upon the natural character of the iron itself.[1]

"The superlative intensity of electro-magnets, and the facility and promptitude with which their energies can be

[1] "I have made a number of experiments on small pieces, from the results of which it appears that much hammering is highly detrimental to the development of magnetism in soft iron, whether the exciting cause be galvanic or any other; and although good annealing is always essential, and facilitates to a considerable extent the display of polarity, that process is very far from restoring to the iron that degree of susceptibility which it frequently loses by the operation of the hammer. Cylindric rod-iron of small dimensions may very easily be bent into the required form without any hammering whatever; and I have found that small electro-magnets made in this way display the magnetic powers in a very exalted degree."

brought into play, are qualifications admirably adapted for their introduction into a variety of arrangements in which powerful magnets so essentially operate, and perform a distinguished part in the production of electro-magnetic rotations; whilst the versatilities of polarity of which they are susceptible are eminently calculated to give a pleasing diversity in the exhibition of that highly interesting class of phenomena, and lead to the production of others inimitable by any other means." [1]

Sturgeon's further work during the next three years is best described in his own words:—

"It does not appear that any very extensive experiments were attempted to improve the lifting-power of electro-magnets from the time that my experiments were published in the 'Transactions of the Society of Arts, etc.,' for 1825, till the latter part of 1828. Mr. Watkins, philosophical-instrument maker, Charing Cross, had, however, made them of much larger size than any which I had employed, but I am not aware to what extent he pursued the experiment.

"In the year 1828, Professor Moll of Utrecht, being on a visit to London, purchased of Mr. Watkins an electro-magnet weighing about 5 pounds,—at that time, I believe, the largest which had been made. It was of round iron, about one inch in diameter, and furnished with a single copper wire twisted round it eighty-three times. When this magnet was excited by a large galvanic surface, it supported about 75 pounds. Professor Moll afterwards prepared another electro-magnet, which, when bent, was 12½ inches high, 2½ inches in diameter, and weighed about 26 pounds, prepared like the former with a single spiral conducting wire. With an acting galvanic surface of 11 square feet, this magnet would support 154 pounds, but would not lift an anvil which weighed 200 pounds.

"The largest electro-magnet which I have yet [1832] exhibited in my lectures weighs about 16 pounds. It is formed of a small bar of soft iron, 1½ inches across each side. The cross-piece, which joins the poles, is from the same rod of iron, and about 3⅞ inches long. Twenty separate strands of copper wire, each strand about 50 feet in length, are coiled round the iron, one above another, from pole to pole, and separated from each other by intervening cases of silk. The first coil is only the thickness of one ply of silk from the iron; the twentieth, or outermost, about half an inch from it. By this mean the wires are completely insulated from each other without the trouble of covering them with thread or varnish. The ends of wire project about 2 feet for the convenience of connection. With one of my small cylindrical batteries, exposing about 150 square inches of total surface, this electro magnet supports 400 pounds. I have tried it with a larger battery, but its energies do not seem to be so materially exalted as might have been expected by increasing the extent of galvanic surface. Much depends upon a proper acid solution. Good nitric or nitrous acid, with about six or eight times its quantity of water, answers very well. With a new battery of the above dimensions and a strong solution of salt and water, at a temperature of 190° F., the electro magnet supported between 70 and 80 pounds when the first seventeen coils only were in the circuit. With the three exterior coils alone in the circuit, it would just support the lifter, or cross-piece. When the temperature of the solution was between 40° and 50°, the magnetic force excited was comparatively very feeble. With the innermost coil alone and a strong acid solution, this electro-magnet supports about 100 pounds; with the four outermost wires, about 250 pounds. It improves in power with every additional coil until about the twelfth, but not perceptibly any further: therefore the remaining eight coils appear to be useless, although the last three, independently of the innermost seventeen, and at the distance of half an inch from the iron, produce in it a lifting-power of 75 pounds.

"Mr. Marsh has fitted up a bar of iron much larger than mine, with a similar distribution of the conducting wires to that devised and so successfully employed by Professor Henry. Mr. Marsh's electro-magnet will support about 560 pounds when excited by a galvanic battery similar to mine. These two, I believe, are the most powerful electro-magnets yet produced in this country.

"A small electro-magnet, which I also employ on the lecture-table, and the manner of its suspension, are represented by Fig. 4. The magnet is of cylindric rod-iron, and weighs 4 ounces. Its poles are about a quarter of an inch asunder. It is furnished with six coils of wire in the same manner as the large electro-magnet before described, and will support upwards of 50 pounds.

"I find a triangular gin very convenient for the suspension of the magnet in these experiments. A stage of thin board, supporting two wooden dishes, is fastened at a proper height to two of the legs of the gin. Mercury is placed in these vessels, and the dependent amalgamated extremities of the conducting wires dip into it,—one into each portion.

"The vessels are sufficiently wide to admit of considerable motion of the wires in the mercury without interrupting the contact, which is sometimes occasioned by the swinging of the magnet and attached weight. The circuit is completed by other wires, which connect the battery with these two portions of mercury. When the weight is supported as in the figure, if an interruption be made by removing either of the connecting wires, the weight instantaneously drops on the table. The large magnet I suspend in the same way on a larger gin. The weights which it supports are placed one after another on a square board, suspended by means of a cord at each corner from a hook in the cross-piece, which joins the poles of the magnet.

"With a new battery, and a solution of salt and water, at a temperature of 190° F., the small electro-magnet (Fig. 3) supports 16 pounds."

In 1840, after Sturgeon had removed to Manchester, where he assumed the management of the "Victoria Gallery of Practical Science," he continued his work, and in the seventh memoir in his series of researches he wrote as follows:—

"The electro-magnet belonging to this institution is made of a cylindrical bar of soft iron, bent into the form of a horseshoe magnet, having the two branches parallel to each other, and at the distance of 4½ inches. The diameter of the iron is 2¾ inches: it is 18 inches long when bent. It is surrounded by fourteen coils of copper wire,—seven on each branch. The wire which constitutes the coils is one-twelfth of an inch in diameter, and in each coil there are about seventy feet of wire. They are united in the usual way with branch wires, for the purpose of conducting the currents from the

[1] Sturgeon's Scientific Researches, p. 113.

battery. The magnet was made by Mr. Nesbit. . . . The greatest weight sustained by the magnet in these experiments is $12\frac{3}{4}$ hundredweight, or 1,386 pounds, which was accomplished by sixteen pairs of plates, in four groups of four pairs in series each. The lifting-power by nineteen pairs in series was considerably less than by ten pairs in series, and but very little greater than that given by one cell or one pair only. This is somewhat remarkable, and shows how easily we may be led to waste the magnetic powers of batteries by an injudicious arrangement of its elements."[1]

At the date of Sturgeon's work the laws governing the flow of electric currents in wires were still obscure. Ohm's epoch-making enunciation of the law of the electric circuit appeared in "Poggendorf's Annalen" in the very year of Sturgeon's discovery, 1825; though his complete book appeared only in 1827, and his work, translated by Dr. Francis into English, only appeared (in Taylor's "Scientific Memoirs," vol. ii.) in 1841. Without the guidance of Ohm's law, it was not strange that even the most able experimenters should not understand the relations between battery and circuit which would give them the best effects. These had to be found by the painful method of trial and failure. Pre-eminent among those who tried was Professor Joseph Henry, then of the Albany Institute in New York, later of Princeton, N.J., who succeeded in effecting an important improvement. In 1828, led on by a study of the "multiplier" (or galvanometer), he proposed to apply to electro-magnetic apparatus the device of winding them with a spiral coil of wire "closely turned on itself," the wire being of copper from one-fortieth to one-twenty-fifth of an inch in diameter, covered with silk. In 1831 he thus describes[2] the results of his experiments:—

"A round piece of iron about a quarter of an inch in diameter was bent into the usual form of a horseshoe; and instead of loosely coiling around it a few feet of wire, as is usually described, it was tightly wound with 35 feet of wire covered with silk, so as to form about 400 turns. A pair of small galvanic plates, which could be dipped into a tumbler of diluted acid, was soldered to the ends of the wire, and the whole mounted on a stand. With these small plates, the horseshoe became much more powerfully magnetic than another of the same size and wound in the same manner, by the application of a battery composed of 28 plates of copper and zinc, each 8 inches square. Another convenient form of this apparatus was contrived by winding a straight bar of iron, 9 inches long, with 35 feet of wire, and supporting it horizontally on a small cup of copper containing a cylinder of zinc. When this cup, which served the double purpose of a stand and the galvanic element, was filled with dilute acid, the bar became a portable electro-magnet. These articles were exhibited to the institute in March, 1829. The idea afterwards occurred to me that a sufficient quantity of galvanism was furnished by the two small plates to develop, by means of the coil, a much greater magnetic power in a larger piece of iron. To test this, a cylindrical bar of iron, half an inch in diameter, and about 10 inches long, was bent into the shape of a horseshoe, and wound with 30 feet of wire. With a pair of plates containing only $2\frac{1}{2}$ square inches of zinc, it lifted 15 pounds avoirdupois. At the same time a very material improvement in the formation of the coil suggested itself to me on reading a more detailed account of Professor Schweigger's galvanometer, which was also tested with complete success upon the same horseshoe. It consisted in using several strands of wire, each covered with silk, instead of one. Agreeably to this construction, a second wire, of the same length as the first, was wound over it, and the ends soldered to the zinc and copper in such a manner that the galvanic current might circulate in the same direction in both; or, in other words, that the two wires might act as one. The effect by this addition was doubled, as the horseshoe, with the same plates before used, now supported 28 pounds.

"With a pair of plates 4 inches by 6 inches, it lifted 39 pounds, or more than fifty times its own weight.

"These experiments conclusively proved that a great development of magnetism could be effected by a very small galvanic element, and also that the power of the coil was materially increased by multiplying the number of wires without increasing the number of each."[1]

[1] Sturgeon's Scientific Researches, p. 188.

[2] Silliman's American Journal of Science, January, 1831, xix. p. 400.

[1] Scientific Writings of Joseph Henry, p. 39.

NOTES AND NEWS.

THE well known writer on vegetable paleontology, Professor E. Weiss of Berlin, died on July 5 last.

—The annual meeting of the American Folk-Lore Society will be held Nov. 28 and 29, 1890, at Columbia College, New York. A preliminary meeting for the purpose of organizing a local committee of arrangements was held at Room 15, Hamilton Hall, Columbia College, 49th Street and Madison Avenue, on Wednesday, Oct. 8, at 4 P.M.

—We learn from the *Medical and Surgical Reporter* of Oct. 4 that there were registered in the second trimester 908 foreigners who were studying medicine in France, of whom 822 were in Paris. Of the latter there were, from Russia, 261; the United States, 159; Roumania, 85; Turkey, 71; England, 51; Spain, 34; Greece, 34; Switzerland, 25; Servia, 20; Portugal, 18; Egypt, 13; Italy, 12; Bulgaria, 8; Austria, 7; Belgium, 7; and Holland, 60.

—By the death of Professor Carnelley the science of chemistry in England has suffered an irreparable loss. It appears, as we learn from *Nature*, that some little time ago Dr. Carnelley had been suffering from an attack of influenza, and it was while returning to Aberdeen after a journey to the south, made with the object of recruiting his health, that he was seized with sudden and severe illness, which was due, as his medical attendants discovered, to the formation of an internal abscess. Surgical aid proved unavailing, the patient's strength gradually gave way, and Dr. Carnelley passed away at mid-day of Aug. 27, at the comparatively early age of thirty-eight.

—The report of Dr. Eitel, inspector of schools in Hong Kong, for the past year, contains some interesting details. According to *Nature*, the total number of educational institutions of all descriptions, known to have been at work in the colony of Hong Kong during the year 1889, amounts to 211 schools, with a grand total of 9,681 scholars under instruction. More than three fourths of the whole number of scholars, viz., 7,659, attended schools (106 in number) subject to government supervision, and either established or aided by the government. The remainder, with 2,022 scholars, are private institutions, entirely independent of government supervision, and receiving no aid from public funds. The total number of schools subject to direct supervision and annual examination by the inspector of schools amounted, in 1889, to 104, as compared with 50 in 1879, and 19 in 1869. The total number of scholars enrolled in this same class of schools during 1889 amounted to 7,107, as compared with 3,460 in 1879, and 942 in 1869: in other words, there has been an increase of 31 schools and 2,518 scholars during the ten years from 1869 to 1879, and an in-